Microbes - the Good They Do

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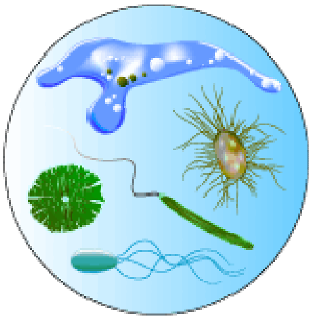

They're on your skin, in your gut and under your nails. The vegetables in your garden cohabit peacefully with them. They dwell in the intestines of cows, exchanging the ability to digest cellulose for sanctuary from the cruel outdoors. In the air, on the land, even in the harshest, most extreme parts of the world where angels fear to tread, they make up more than two-thirds of the world's biomass - and yet people are generally ignorant of their existence or, at best, have thoroughly warped notions of the role they play in the big drama of life.

We are, of course, talking about micro-organisms.

What Are Micro-organisms?

To put things loosely, they are living creatures that are too small to be seen by the naked eye. The term 'micro-organism' covers two groups of creatures:

- **Prokaryotes** - organisms with no nuclei in their cells, which resemble ancestral microbes that crawled out of the primordial soup. This group includes bacteria and blue-green algae (cyanobacteria). The latter were in abundance early in the history of the Earth, covering most of its surface with brightly coloured patches of purple, green, blue and red.
- **Eukaryotic micro-organisms** - microscopic organisms with 'true' nucleated cells, such as protoctists, algae and fungi. Humans, cows, plants and every other living creature you can see are also eukaryotes, only they are macroscopic.

The role micro-organisms play in the environment is enormous - indeed, the world could not possibly last long in the absence of micro-organisms. It is these creatures that are responsible for clearing away the debris on the stage of life to make way for new sets and new props, for generating and recycling most of the chemicals that would otherwise be lost to the ecosystem through biological processes, even for promoting the evolution that is so crucial to life. It is highly unfortunate, therefore, that the primary and secondary education systems have all but neglected them in favour of the macroscopic minority - the plants and animals that are more easily seen by the casual observer.

But micro-organisms have been here for millions of years, before the first multicellular creature crawled out of the primordial soup, and will probably be here long after all other life has been exhausted or extinguished. It is therefore time to put the importance of micro-organisms back into perspective, and to acknowledge them for their positive contribution towards the continuity of this thing we call life.

Microbes and Planet Earth

Long before dinosaurs ruled the world and man came forth and built his concrete jungles and satellites, back in a time where the Earth was still burning off the heat of its creation and geysers and volcanoes gushed aplenty, there were microbes. These were the descendants of the simple replicating machines that rose out of the rich primordial soup that covered most of the Earth - strings of DNA or RNA in small protective sheaths and had 'discovered' how to make copies of themselves out of the raw material from which they themselves were made.

Centuries after Charles Darwin put forth his theory of evolution in *On The Origin of Species*, many people still reject outright the notion that we, superior beings of this world, have ancestors as humble

- as *lowly* - as the tiny, blind, one-celled creatures who teemed in the organic soup more than three billion years ago. In many cases it may be that we cannot imagine being related to the microscopic lifeforms of today, who lie ignored except where they can be blamed for everything from disease to destruction.

Yet the fact remains that many of the structures in the cells of multicellular entities were, many millions of years ago, independent life-forms that had been engulfed by bigger primordial cells but somehow managed to make a living with them instead of getting eaten. Later, these primordial cells came together by accident and, where there was mutual benefit, formed permanent unions. Specialisation evolved over time as different cells came together, with tasks divided between them. Eventually, they formed multicellular organisms, which grew steadily more complex as they adapted to their environment, differentiating and evolving into what we all are today[1].

Microbes and the Consumer Market

Mankind had learned to harness the power of microbes in the production of food long before Anton van Leeuwenhoek gazed into his first crude microscope. The relationship between brewers and yeast began over 6,000 years ago in Mesopotamia. Around 4,000 years later, people discovered fermented curds in their milk pouches, and the cheese industry was born. Rome had a booming cheese industry, as did European abbeys later, most of which had their own secret recipes.

Today, micro-organisms are found at the heart of industry. The versatile baker's yeast is not only used in breadmaking, but also in the production of alcoholic drinks. *Lactobacillus acidophilus* is a common name in the household - who has not heard of it, as its name appears in practically every yoghurt commercial? Swiss cheese would not be Swiss cheese without the fermenting bacterium *Propionibacterium*, nor would blue cheese and Roquefort have their pungent smell and sharp taste without *Penicillium*, a cousin of the famous penicillin mould.

Vitamins, used as supplements for human food and animal feeds, are also produced commercially using a host of bacteria, yeasts and fungi. Important food flavourings, such as monosodium glutamate (MSG) and the artificial sweetener aspartame, rely heavily on the fermentation processes of microbes such as brevibacteria. We would never have had vinegar for our salads if not for our famous baker's yeast and a host of anaerobic bacteria fermenting carbohydrates to acid. One microbe's waste is another man's food.

In the medical industry, genetically-modified bacteria are engineered to carry the gene for insulin, and to produce insulin in bulk for people with insulin-dependent diabetes. The manufacture of otherwise ludicrously expensive steroids for treating autoimmune disease, alleviate allergies and treate skin diseases depends heavily on micro-organisms to transform chemical molecules. Consider the steroid cortisone, which is used to treat rheumatoid arthritis. This steroid can be produced by non-biological means in the laboratory, converting deoxycholic acid from bile by submitting the starting material to no less than 37 different chemical reactions to produce the steroid. This incredibly tedious procedure had a pathetic yield of 0.15%. The alternative - extracting about 100mg of the steroid from approximately 6,000 head of cattle - brought the price of the drug to about $200 per gram in the 1940s. Compare this with the production using the mould *Rhizopus arrhizus*, which requires only six steps to completion, and which brought the price of cortisone down to $6 per gram in the late 1940s, and to $0.46 by 1980.

Enzymes are catalysts of most chemical and biochemical reactions. Synthesized enzymes would be too costly and impractical in the long run; micro-organism-produced enzymes are used instead, being far more useful because they are a great deal more discriminating than chemical catalysts. Microbial enzymes are added to detergents to enhance their power as stain-removers and colour restorers. Others are sold commercially and used to ripen fruit for sale. Be it in the textile or food industry,

microbial enzymes are the key. And after all, where would the cola industry be if not for these microbes?

But micro-organisms are not important in industry only as producers and bioconverters. The latest food fads have introduced a whole variety of algae and fungi as food. Visit any supermarket and you are likely to come across cereal drinks fortified with *Spirulina* and *Chlorella*. Some armies, being the thoroughly resourceful forces that they are, feed *Torula utilis* to their soldiers in bulk. These single-celled protein foods may look unappealing, but many are nutritious and they are a very good source of protein.

And of course, most of us - and not just hobbits - love mushrooms. It may surprise some that the unmistakably visible mushrooms are classified under the heading 'micro-organisms'. This is because mushrooms are actually groups of filamentous fungi that form prominent, complex structures called fruiting bodies, which are largely responsible for the fungi's reproduction.

Microbes and the Magic Bullet

Any decent microbiologist will tell you that fungus on a bacteria culture plate spells nothing short of disaster. There is no greater nightmare than finding happy green patches of mould where colonies of bacteria should be. Alexander Fleming may have felt the same way in 1928, when he entered his laboratory and found them growing on his precious plate of staphylococci. However, we should be grateful that he was calm enough to sit down and observe them instead of tossing the plate into the wastebasket in cold fury - we would never have had penicillin if he had!

Microbes had long since been used in the medical field to treat non-life-threatening conditions. Medical records from China, Egypt and Mesopotamia dating from 1500 BC report the use of mouldy and fermented substances from dung and soybean curd to treat superficial wounds and swelling. However, back then, nobody knew the real cause of infectious diseases, and this prevented the booming of the antibiotics industry. In 1874, Englishman William Roberts observed that the growth of bacteria was impeded by fungi and vice versa. Later, Louis Pasteur and Jules Francois Joubert noticed that anthrax bacilli refused to grow in the presence of mould.

It wasn't until after 1928, however, that penicillin and antibiosis were 'discovered'. Another 12 years or so elapsed before Howard Florey and his collaborators successfully purified penicillin and administered it to a desperately ill police constable[2]. This was the beginning of the drug's reputation as the 'magic bullet'.

Today, penicillin is no longer as useful as it once was. After more than 70 years of research, however, we now have an enormous selection of antibiotics produced by a wide variety of micro-organisms ranging from bacteria to fungi. Many of these antibiotics have been engineered to target a wide range of pathogens, and are many times more potent than their humble ancestor, penicillin.

Microbes in Biological Research

There is a relatively new technology in the field of genetics called 'polymerase chain reaction'. It is, in a nutshell, a process of making copies of pre-existing DNA[3]. The original donor of the enzyme that makes this technique possible is the humble laboratory pet *Escherichia coli*, which has a somewhat tarnished reputation thanks to its insane mutant cousins, E coli, who have killed many innocent people who ate undercooked beef.

Micro-organisms are playing an increasingly huge role in biological research. Bacteria have been engineered to carry genes of other organisms, some of which are transferred to the bacteria by specially-bred viruses. Hybrids are made by coupling fungi that possess a certain trait with those that

do not. New combinations of genes are studied. These may sound like hideously cruel things to do to such benign creatures, but it is a necessary step to a greater understanding of genetics.

What is the use of playing around with the genetic content of micro-organisms? For one thing, microbes multiply a great deal more rapidly than multicellular animals[4]. This enables researchers to get many copies of a gene - or its products - in a relatively short period of time. This is how we currently get insulin for people with diabetes - by cloning the gene manufacturing insulin into bacteria, and letting them do the dirty job of producing this chemical for us. Many other micro-organisms have also been engineered to be more efficient in biotechnology - producing greater yields in the antibiotics industry, for instance.

The study of microbial genetics - again, possibly because microbial reproduction and multiplication happen so fast - also enables scientists to understand gene function, which is the basis of cell function and the key to understanding why a great many diseases - such as cancer - happen. You may argue that the microbes are only playing a passive role in these studies, but if not for them we would still be in the 'dark ages' of medicine.

Microbes as Symbionts of All Living Things, and Components of the Biogeochemical Cycle

We are not alone.

Every inch of every surface of our body is covered with micro-organisms. Billions of them thrive on our skin. Millions are found elsewhere inside us, predominantly inside our intestines. Everything around us is similarly coated with probably as many cells as there are atoms in the universe. We are, in a way, *made* of microbes.

But what is there to be afraid of? They have been with us from the moment we were born - colonising our bodies within the first 30 minutes of birth - and they will be there when we die, to take us apart into useful chemicals to be re-circulated in the environment. And we are not the only ones living with micro-organisms. Every other living creature on the face of this Earth shares its life with zillions of microscopic neighbours.

The role microbes play as symbionts of living creatures is enormous. What once were micro-organisms have through time become integrated into the cells of multicellular life forms, becoming the powerhouses of cells. Microbes in our intestines help produce certain essential vitamins such as vitamin B12. Others toil in the guts of ruminant animals, thus granting these creatures the ability to derive nutrition from grass and other cellulose-containing material[5]. Bacteria such as *Agrobacterium* living in the nodules of leguminous plants (eg, peas, beans and clover) convert the otherwise inaccessible nitrogen from the air into readily usable forms for plant growth and construction of new tissue. Fungi associated with the roots of plants in relationships called mycorrhizae encourage the growth of plants by increasing absorption surface, reducing water stress, gathering nutrients and making the roots more resistant to infection.

Hosts of micro-organisms attack freshly dead plants and animals, reducing their corpses to elements to be returned to the environment from which they were born, making grounds more fertile for growth and giving other creatures the necessary ingredients for getting on with life. This is the basis of composting, which harnesses the power of microbes to degrade organic matter into fertile plant stuff. Micro-organisms involved in the phosphate cycle and various other chemical cycles ensure that the soil is rich in chemicals for plant growth. Micro-organisms living on the surfaces of our bodies and those of other living things confer protection by playing an active role in encouraging the maturation of our immune system, and denying disease-causing microbes the foothold they need to colonise our bodies and do damage.

In fact, micro-organisms have become such an important part of all our lives that to remove them would spell imminent death for us.

Microbes as Producers of Oil

About the most popular commodity available today is petroleum. Not only is it the reliable source of energy that fuels most of our vehicles, petroleum is also used as raw material in the plastics and synthetics industry. Because everybody needs petroleum, countries that have large oil traps or reserves are disgustingly rich.

Most of us are taught in school that petroleum is formed over the course of many million years deep within the earth's crust, where the high temperatures[6] and pressure shaped and altered organic material into the slick black substance that is so prized in the world today. However, most of our teachers probably never told us that micro-organisms were very deeply involved in the making of oil, or even mentioned them in passing.

Among those microbes involved in the formation of oil are stromatolites, which are mats of filamentous blue-green algae[7]. The largest known deposits of oil shale in the world - the Green River Formation in Colorado-Wyoming, USA - harbours an abundance of their fossil remains, dating back to about 3,000 million years ago. These humble micro-organisms supplied the fats that would over time be converted into the hydrocarbons comprising crude oil. Scientists have established that microbes were the workforce behind the production of oil, but are still unsure of exactly how.

If the exact process of petroleum synthesis by microbes is unknown, the role of microbes in facilitating recovery of oil is an established fact. Some micro-organisms produce carbon dioxide gas, which propels oils upwards from otherwise exhausted wells. Xanthan gum produced by *Xanthomonas campestri* is also highly useful in loosening oil that stubbornly clings to underground rock particles.

Scientists are currently studying algae mats at the bottom of permanently ice-covered lakes in Antarctica in an attempt to understand how petroleum formation by microbes happens in nature. Who knows, maybe one day when the mystery is solved we will have giant oil farms, where the large population of workers will be mats of blue-green algae.

Microbes as Mediators of Decomposition and Bioremediation

Recently, Singapore's decision to stop relying on water supplies from Malaysia and to recycle their own waste water has provoked scepticism and derision from the South-east Asian community. It is certainly not the first country to take up the initiative, nor will it be the last. And despite jokes of finding corn in Singaporean water, we must acknowledge the fact that they are harnessing the powers of micro-organisms in bioremediation.

Brock Biology of Microorganisms defines waste waters as:

...materials derived from domestic sewage or industrial effluents...

Most of us just tend to think of it as, er, 'excrement cocktail'.

Whatever we may call it, waste water is a problem. Because of public health, recreational, economic and aesthetic considerations, it is in highly bad taste to merely dispose of waste water into natural water systems without first processing them. You do not want your drinking water to taste of sewage. You do not want to get food poisoning because your water supply is contaminated with human waste.

This is where microbes come in, accepting this horrendously gross cocktail of waste and breaking down the organic substances into simple ones, turning crud into water that is pure enough to be released into rivers or channelled into tanks for chlorination before it once again becomes drinking water. The complex organic chemicals are themselves recycled and returned to the environment in the form of ammonia, carbon dioxide and nitrate, and perhaps a variety of other gases. What is left of the organic compounds is a solid residue that is sold off as fertilizer.

The role of micro-organisms as bioremediators was discovered in the early 1930s by Marjory Stephenson, a researcher at the University of Cambridge, who observed that microbes in a river that had been contaminated with effluent from a sugar-beet factory were digesting enormous quantities of the waste, mainly into gases. She later collaborated with LH Stickland to demonstrate that these gas-producing bacteria were producing an enzyme that somehow activated hydrogen. It is now known that this family of enzymes, called hydrogenases, catalyse a wide range of processes accompanied by the evolution or consumption of hydrogen, and that such activities are important in recycling organic matter in the environment. These hydrogenase-producing bacteria are highly valuable scavengers in the ecosystem because of their incredible contribution to bioremediation, breaking down organic matter to safer substances.

And then consider the case of the Arabian Gulf, into which was poured 500,000 tonnes of crude oil in 1990[8]. Panicking ecologists and the media foresaw the mass obliteration of life forms in the region. But they were wrong. By the end of 1992, blue-green mats of microbes embedded in mucilage had sprung up all over the oiled intertidal areas of the Gulf, the first signs of self-cleansing. Each gram of a cyanobacteria mat contains up to a million cells of bacteria capable of digesting oil. Although it is doubtful that cyanobacteria can themselves degrade oil, they are useful nevertheless because they provide the oil-gobbling bacteria with both oxygen and protection from being washed away into the open sea. Two researchers conducting studies in Nigeria in 1993 also described an oil-utilising fungus, *Aspergillus niger*. Studies carried out in the Lagos Lagoon have also shown that a variety of bacteria, including *Micrococcus* and *Pseudomonas*, have been responsible for cleaning up the waters following repeated spillages.

Being neither capable nor willing of cleaning up large messes, we should thus be grateful that there are such microbial consortia around to do our dirty jobs for us.

Let's Hear it for the Good Guys

When the word 'microbes' is mentioned, people have the tendency to think of damage and disease, yet science and nature have shown us that, without these micro-organisms, life on Earth would not be possible. While it may be true that there are some micro-organisms that are capable of making life miserable for us all, the fact remains that the majority of micro-organisms are benign, or do us a great deal of good by colouring our world and making life more interesting. Therefore it is time for us to stop putting the blame on micro-organisms for every detriment that occurs, and accept the multitude of good ones as symbionts in our lives, in a world that is too big for us alone.